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EFFECT OF LOADING DENSITY ON THE HOT WIRE INITIATION OF NORMAL LEAD STYPHNATE AND BARIUM STYPHNATE

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ABSTRACT: Experiments were conducted to determine the effect of density on the required hot wire ignition energy and firing time of normal lead styphnate and barium styphnate. It was found that the ignition energy remained constant and the average ignition time decreased as the loading density was increased. It is postulated that changes in the thermal resistance between the wire and the explosive are responsible for the differences in the time of ignition. A faster transfer of energy to the explosive decreases the time the wire can act as an initiating stimulus when heated by a capacitor discharge and hence decreases the possibility of delayed ignitions.

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EFFECT OF LOADING DENSITY ON THE HOT WIRE INITIATION OF NORMAL LEAD STYPHNATE AND BARIUM STYPHNATE

This report describes the results of an investigation on the effect of loading density on the ignition energy and time of ignition of two styphnate explosives. The work was performed under Task ORD 332-001/UF17 354 309 P.200.

The results should be of interest to persons engaged in initiation research and in the design of electric initiators and power supplies therefor.

The identification of commercial materials implies no criticism or endorsement of these products by the U. S. Naval Ordnance Laboratory.

GEORGE G. BALL
Captain, USN
Commander

C. J. ARONSON
By direction

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INTRODUCTION

1. The effective utilization of explosives and explosive trains requires a thorough understanding of the initiation process and the growth of explosion. Many factors affecting the initiation of explosives in initial explosive components have not been explained. Further study of these factors, both chemical and physical, is needed in order to build safe, reliable, and effective fuze trains.

2. The purpose of this investigation was to examine the effects of loading density on the hot wire ignition of normal lead styphnate (NLS) and barium styphnate. NLS is a widely used sensitive primary explosive. It is considered a relatively poor initiating agent, but is easily ignited by a hot wire and hence widely used in electric initiators. In spite of the wide usage of NLS, relatively little is known about the effect of loading density on its ignition characteristics other than that the energy required for its ignition remains fairly constant over a wide range of loading pressures. Relatively little is also known about the effect of loading pressure on the ignition properties of barium styphnate, a material which is being considered as a substitute for NLS in high temperature applications.[1,2] *

* References are given on page 10.

EXPERIMENTAL

3. The apparatus used in this investigation has been previously described in NOLTR 69-148[3]. It is capable of sensing the time of initial reaction in explosives heated by a hot wire and of relating this time of initiation to the electrical signal heating the wire. The essential parts of the experimental apparatus are described below:

<u>Firing Circuit</u> - The firing circuit is shown in Fig. 1. A coaxial current shunt is inserted in the circuit in series with the bridgewire to monitor the current waveform to the bridgewire. The firing circuit parameters are:

C = 1.0 microfarad

R = 0.32 ohm

L = 1.56 microhenries

V = variable (volts)

<u>Initiator Plug</u> - A standard two pin phenolic initiator plug was specially modified to observe the initial reaction of the explosive. A hole was drilled axially through the initiator plug between the two pins and a light pipe potted in this hole with transparent epoxy cement. See Fig. 2. The excess cement and light pipe fibers were trimmed flush on the plug surface with a razor blade. Then a 1-mil diameter nichrome wire was soldered in place. The bridgewire resistance (2.5 - 4 ohms) is sufficient to overdamp the circuit so that the bridgewire receives an overdamped current pulse from the capacitor. An aluminum charge holder to contain the explosive was force fitted on the plug to complete the initiator plug assembly.

Light Pipe - The light pipe used is flexible "Crofon" light guide developed by E. I. duPont de Nemours and Company. The fibers are plastic and transmit wavelengths from 3100 to 11,000Å. An outer protective jacket is peeled off of the section inserted into the initiator plug. The length of the light pipe, less than 2 ft., is kept as short as possible in the experimental set-up since there is a 9% loss of light per foot for the first 9 feet.

Detectors - The radiation transmitted by the light pipe is detected by a photomultiplier tube with a high frequency response. Two types of photomultiplier tubes are used, an RCA-931A which has a maximum response at 4000Å and an RCA-7102 which has a maximum response at 8000Å. A filter is used with the RCA-7102 to eliminate a spurious response in the UV region.

Recorder - A Tektronix 555 dual beam oscilloscope with 2 fast-rise Type K preamplifiers was used to observe the current and photomultiplier tube signals. The oscilloscope is triggered by the current signal and the photomultiplier is used to observe the light or heat emitted at the bridgewire/explosive interface, depending upon which tube is employed. A block diagram of the experimental arrangement is shown in Fig. 3.

4. The criterion for initiation using this method, along with limitations and detection limits of the RCA-931A and RCA-7102 photomultiplier tubes, are discussed in Appendix A.

EXPERIMENTAL RESULTS

Hot Wire Sensitivity

5. Fifty shot Bruceton tests[4] were used to investigate the hot wire sensitivity of NLS and barium styphnate. Previously run Bruceton tests had shown that the 50% threshold ignition requirement for NLS does not change over a loading pressure range of 10,000 to 60,000 psi. (See Table I.) Present tests with NLS over a loading pressure range of 2,500 to 60,000 psi exhibited the same effect. Bruceton tests with barium styphnate were conducted over a loading pressure range of 2,500 to 60,000 psi and also showed the same constant energy requirement over the loading pressure range. Barium styphnate required approximately 1½ times the energy necessary for the ignition of NLS. A summary of the Bruceton test results with styphnates is given in Table I along with available analogous data for basic lead styphnate. It appears that the commonly used styphnates show no change in hot wire sensitivity over a wide range of loading pressures.

Time of Ignition

6. The ignition time was investigated using the apparatus described. The effect of loading pressure on the ignition time of NLS was investigated at two different energy input levels (calculated 99.9% and 150% of calculated 99.9% firing energy). Initial detection shots were made using the RCA-7102 photomultiplier tube and the runaway reaction or rapid evolution of heat was considered as the ignition time. See Fig. 4 for typical oscillograms. The times of ignition at three different loading pressures are shown in Fig. 5 for the two energy input levels. Five shots were also made at each loading pressure at the lower energy level input using the RCA-931A photomultiplier tube as the detector. The detection signal is fairly similar to that obtained with the RCA-7102 photomultiplier tube. See Fig. 6. These times are also included in Fig. 5. It can be seen that the ignition times show a definite decrease with increasing loading pressure. With the capacitor charged to 65 volts, the minimum observed ignition times decrease as the loading pressure is increased. At the 80 volt charging level, the minimum ignition times are fairly constant over the loading pressure range, and thus it appears that for practical purposes at that level the minimum hot wire ignition time limit has been reached.

7. The effect of loading pressure on the ignition time of barium styphnate was investigated over the same loading pressure range as NLS. After a few trial shots, it was decided to use the RCA-931A photomultiplier tube as the detector since in certain cases it was difficult to decide the time of ignition with the RCA-7102 photomultiplier tube. This was so because of the very gradual heat emittance observed in some shots with barium styphnate. See Fig. 7. Since the wire heat is also observed at the voltage level employed, it is difficult to decide exactly when ignition commences because of the slow build up of barium styphnate. When the RCA-931A photomultiplier tube is used, it is fairly easy to measure the ignition time of barium styphnate even when observing a slow build-up. See Fig. 8. Measurements on the barium styphnate records show the same trend as with the NLS. See Fig. 9. Though the ignition times are of the same order of magnitude as those of NLS, the propagation rate of barium styphnate is much lower. At the 10,000 and 60,000 psi loading pressures, gas pressure build up in back of the burning front can blow the charge holder off the plug before the barium styphnate is entirely consumed. The sudden pressure drop and/or cooling extinguish the burning front at the time of blow-off leaving a small column of unburnt explosive in the charge holder. This indicates that if barium styphnate is employed as an igniter material on the bridgewire, the explosive device should be designed to prevent any movement or quenching of the barium styphnate column.

DISCUSSION

8. Persons associated with electroexplosive devices are quite familiar with the phenomenon that the functioning time (time from beginning of energy input to measurable indication of explosive output) is dependent upon the rate at which energy is applied to the device. For example, Fig. 10 shows the effect of the constant current level on the functioning time of a typical electroexplosive device, the Mk 57 Mod 0 Detonator. It can be assumed that the changes in functioning time are largely due to the ignition element of the electroexplosive device. It can be seen from Fig. 10 that long functioning times are usually associated with a low rate of energy input and short functioning times with a high rate of energy input (in non-delay items). The same type of effect can be seen in Fig. 5 by comparing the times for the two energy inputs at any single loading pressure.

9. The experimentally observed variation in "ignition time" with loading density however cannot be associated with the energy input since the ignition energy requirement was found to remain constant over the loading pressure range investigated. The following explanation is proposed for the reason much longer ignition times are observed with styphnates at the lower densities.

10. In 1960, L. Rosenthal, after heating a wire with a half sine wave energy burst, passed a small monitoring current through the wire so that the resistance variation can be followed during the cooling period as shown in Fig. 11[5]. It can be seen that the wire will reach a higher temperature when surrounded by a material of low heat capacity (air). When plaster of Paris is pressed on the wire, the wire does not reach as high a temperature as in air and cools at a faster rate. When the plaster of Paris is water set to provide better thermal contact with the wire, the peak wire temperature reached is lower yet, and the cooling occurs at a faster rate. It can be seen that though practically the same amount of energy* is dumped into the wire, the temperature excursion of the wire is governed by the thermal coupling with the surrounding material.

*In actuality, there are slight energy differences since the resistance of the wire influences the RC time (energy delivery rate) and also the ratio of the available energy absorbed by the wire to that dissipated in the circuitry. A higher resistance will lengthen the RC time and effect a slower delivery of energy, but will result in more energy being delivered to the wire. However, the energy differences can be considered negligible since a 200°C temperature difference would change the nichrome wire resistance only 3%.

11. The Rosenthal cooling curve generator[5] was used to examine the effect of the NLS loading pressure on the temperature excursion of the wire. A 7-microsecond wide half sine wave energy burst was used to heat the NLS loaded wires and a 50-milliampere trickle current was used to observe the cooling curves. The burst energy was limited in order to stay below the ignition temperature of the NLS. See Fig. 12. Though the cooling curves were examined below the ignition temperature of NLS, they would be analogous to those obtained at higher energy input levels.

12. If in the actual firing tests the assumption is made that the wire temperature excursions are above the NLS ignition temperature, a line representing the ignition temperature can be drawn across the cooling curves as shown in Fig. 12. The line is drawn with a downward bias since the ignition temperature is not a characteristic property of an explosive and has been observed to decrease with the time of heat exposure. If a second assumption is now made that the wire can act as an initiating stimulus only when its temperature is above the ignition temperature of the explosive, it can be seen that the wire in poorest thermal contact with the explosive can act as an initiating stimulus for a much longer period. Any ignitions occurring after 15 microseconds (nominal 5 RC time)* for the experimental conditions employed, occur on the cooling curve since the wire was previously found to reach its maximum temperature during the latter part of the capacitor discharge. It appears that the long ignition times observed can be attributed to a slow heat transfer from the wire to the explosive.

13. Following the above reasoning, it would be natural to expect fast ignition times when the explosive is in good thermal contact with the wire, i.e., with the explosive compacted well against the wire. Since fast ignitions can also be observed with low density explosive, the foregoing appears to be only part of the explanation. One can surmise that even with low density explosive around the wire, occasional granules of the explosive can have good thermal contact with the wire and poor contact with adjacent granules. Occasionally these granules could ignite as quickly as the densely packed explosive since they will also closely follow the initial temperature rise of the wire (which will be higher with low density explosive). If the number of granules ignited is sufficient, an immediate propagation can commence. In some of the oscillograms obtained with the RCA-7102 photomultiplier tube, there is an indication of a slower heat evolution occuring before the rapid evolution of heat commences. See Fig. 13a. The signal from the RCA-7102 detector tube is not definite proof itself of a low level reaction

*Though the time required to discharge a capacitor is theoretically infinitely long, for practical purposes a capacitor is considered to be fully discharged after 5 time constants (5 RC).

since there is a possibility that it could also be an indication of wire heat. Occasional oscillograms with the RCA-931A show a faint emittance of visible light for a period before the intensive emittance. See Fig. 13b. It is believed that this faint emittance can represent a localized decomposition. It appears that at the lower densities the propagation can either start immediately if a sufficient number of granules are ignited, or if too few granules are ignited the explosive can undergo a localized decomposition for a number of microseconds before propagation proceeds outward from the wire/explosive interface. At the higher densities, ignition is practically simultaneous with immediate propagation.

14. In the examination of the energy coupling from the wire to the explosive, it should be noted that even for fast electrical inputs, the heat capacity cannot be considered to be that of the bridgewire alone. See Table II for heat capacity and cooling time constant measurements made with the cooling curve generator. Not only does the heat capacity of the bridgewire system increase as the explosive loading pressure is increased, but the heat loss factor also rapidly increases. Since no two items are completely identical due to particle arrangement and compaction differences of the explosive around the bridgewire, it is difficult to predict the type of thermal pulse transmitted to the explosive. This puts a practical limit upon the use of mathematical equations to predict or analyze the initiation process. The actual thermal pulse transmitted to the explosive (which is partially governed by the thermal contact with the explosive) is the determining factor as to if and when a propagating initiation will take place.

15. The experimental data show that the energy requirement for the ignition of barium styphnate and NLS remains practically constant over a wide range of loading pressures even though the heat capacity of the bridgewire system increases with loading density. One factor which might contribute to the ignition energy constancy is the difference in the rate of heat transfer to the explosive at different densities. At the low loading pressures the heat loss to the inert parts such as the phenolic plug and the solder contacts can be fairly considerable because of the slower heat transfer to the explosive. At the higher densities, less heat loss would be expected to the inert parts because of the quicker heat transfer to the explosive. It was previously determined that there is some heat loss to the interstitial air at the lower loading densities[6]. See Fig. 14 for a postulated energy division. Other possibilities also exist for the constancy of the ignition energy. For example, the greater amount of explosive in proximity to the bridgewire at the higher densities may not have to be raised to as high a temperature as the low density explosive in order to produce an approximately equal number of hot spots. Though the natural tendency is to try to reduce the constant ignition energy explanation to a single consideration such as the heat transfer division, the phenomenon upon further investigation may prove to be far more complex.

CONCLUSIONS

16. The hot wire ignition energy of NLS and barium styphnate remains constant over a loading pressure range of 2.5 to 60 K psi.

17. Care should be taken when using a column of barium styphnate as the ignitor charge in hardware to insure that no movement of the explosive column takes place. If care is not exercised movement can occur from the large gas pressure build up behind the burning front and can lead to quenching of the burning reaction.

18. The average ignition times of NLS and barium styphnate show a definite decrease with increasing loading pressure.

19. The thermal pulse transmitted from the wire to the explosive is partially governed by the thermal contact of the wire with the explosive.

20. Poor thermal contact between the wire and the explosive can cause long ignition times and conversely good thermal contact will give shorter ignition times. Good thermal contact will also decrease the ignition time spread and can advantageously be employed along with higher power inputs where uniform ignition times are desired.

21. There is a minimum hot wire thermal ignition time dependent upon the thermochemistry of the particular explosive employed. This minimum limit can be approached by increasing the power input level or by improving the thermal contact between the wire and the explosive.

REFERENCES

1. Atlas/Aerospace, No. 5, Feb. 1969 and No. 8, Dec. 1969, Atlas Chemical Industries, Inc., Valley Forge, Pa.

2. Thermex II Product Data Sheet, Northrop Carolina, Inc. Asheville, N. C.

3. Leopold, H. S., "A New Technique for Detecting the Initial Reaction of Primary Explosives Initiated by Hot Wire", NOLTR 69-148, Nov. 1969.

4. "Statistical Analysis for a New Procedure in Sensitivity Experiments", AMP Rept. No. 101.1R SRG-P, No. 40, 1944; a report submitted by the Statistical Research Group, Princeton University.

5. Rosenthal, L. A. "A Cooling Curve Generator and Its Application to Electroexplosive Device Studies", NAVWEPS Rept. 7313, Dec. 1960.

6. Leopold, H. S. "Effect of Reduced Ambient Pressure on the Hot Wire Sensitivity of Primary Explosives, Metal-Oxidant Mixtures, and Black Powder", NOLTR 68-199, Jan. 1969.

TABLE I

EFFECT OF LOADING PRESSURE ON 50% FIRING ENERGY (ERGS)*

	Loading Pressure (K psi)				
Explosive	2	2.5	10	30	60
NLS		15,400	15,700		15,800
NLS**			16,600	16,900	16,200
BLS ***	14,300		14,600	15,000	
Barium Styphnate		24,900	24,200		24,400

* Bridgewire - nichrome, 1 mil diameter, 50 mils length, 2-4 ohms.

** From previous testing - same bridgewire, but lower resistance range (1.7 - 2.7 ohms), used in different firing circuit with higher circuit resistance.

*** Basic Lead Styphnate.

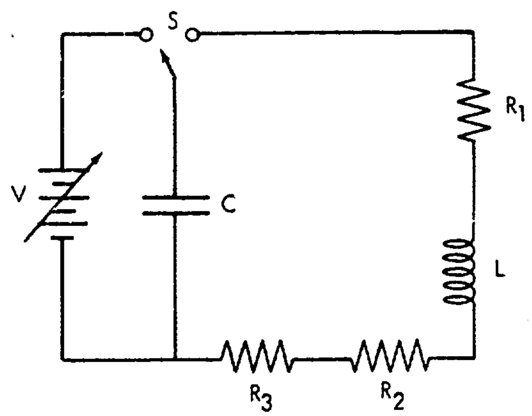
TABLE II

HEAT CAPACITY AND COOLING TIME CONSTANT MEASUREMENTS

Bridgewire Condition	Heat Capacity (microwatt-sec/°C)	Ratio to Bare Wire Heat Capacity	Cooling Time Constant (microsecond)
Bare* (air)	2.47	1.00	9700
NLS (2.5 K psi)**	3.16	1.28	2600
NLS (10 K psi)**	3.77	1.53	2000
NLS (60 K psi)**	4.75	1.92	1400

* Average of 6 items.

** Average of 4 items.



C - CAPACITOR - 1.0 MICROFARAD
S - SWITCH - MERCURY/MERCURY CONTACT
L - CIRCUIT INDUCTANCE - 1.56 MICROHENRIES
R_1 - CIRCUIT RESISTANCE - 0.31 OHM
R_2 - COAXIAL CURRENT SHUNT - 0.010 OHM
R_3 - BRIDGEWIRE - 2.5 TO 4 OHMS

FIG. 1 FIRING CIRCUIT

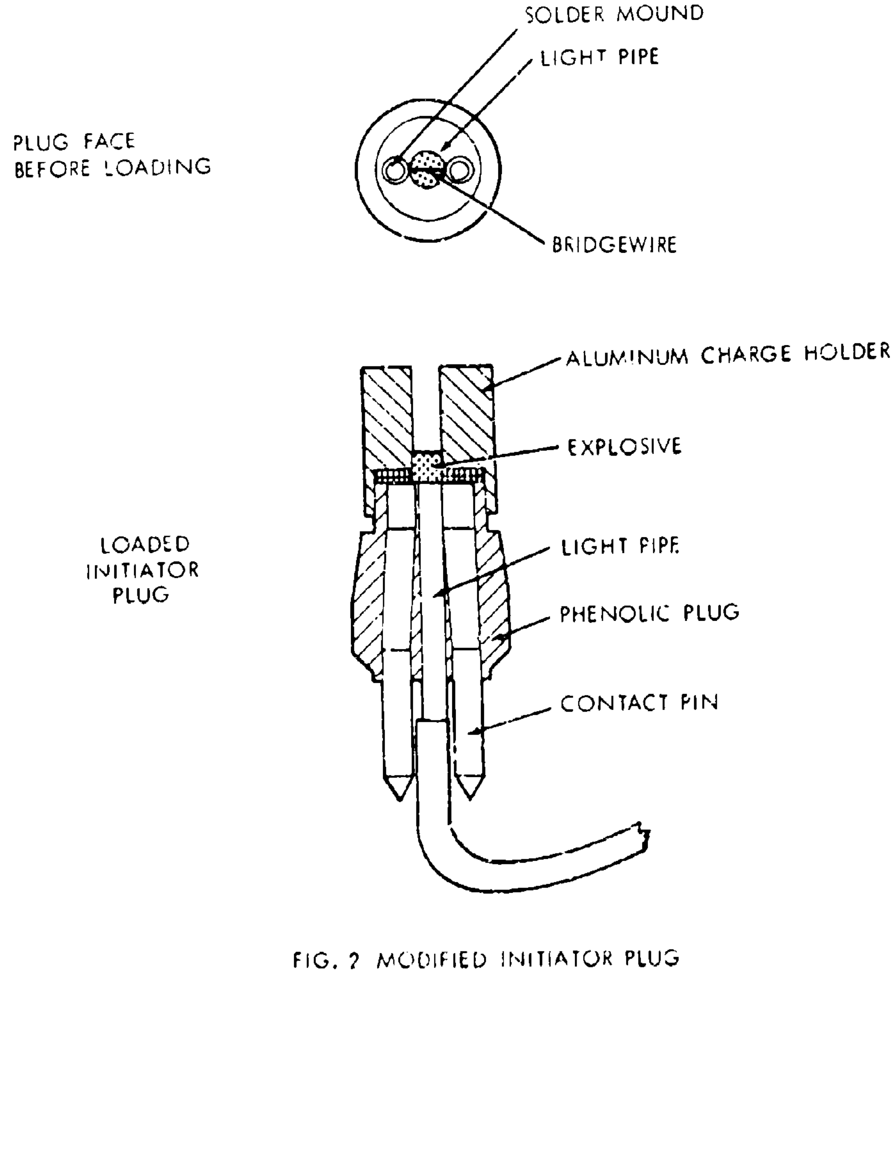


FIG. 2 MODIFIED INITIATOR PLUG

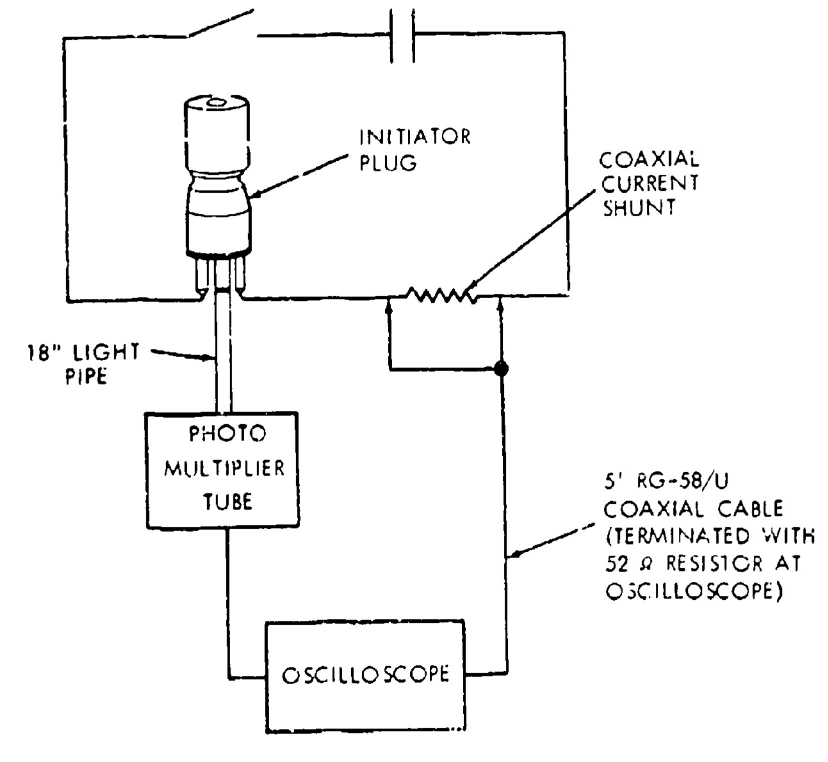
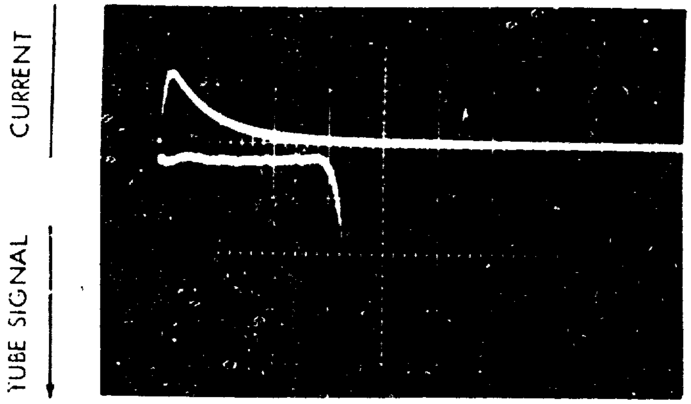
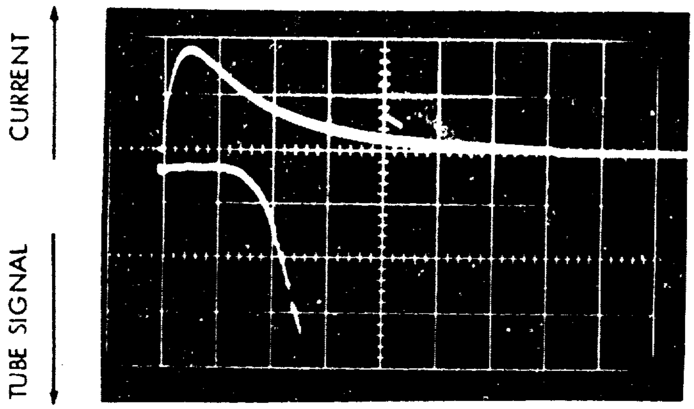


FIG. 3 TEST ARRANGEMENT



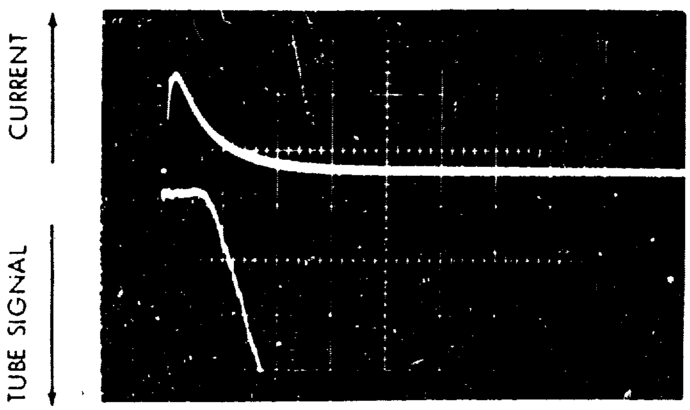
LOADING PRESSURE - 60K PSI
CAPACITOR VOLTAGE - 65 VOLTS

SWEEP SPEED - 5μ SEC/DIV



LOADING PRESSURE - 60K PSI
CAPACITOR VOLTAGE - 80 VOLTS

SWEEP SPEED = 2μ SEC/DIV



LOADING PRESSURE - 2.5K PSI
CAPACITOR VOLTAGE - 80 VOLTS

SWEEP SPEED = 5μ SEC/DIV

FIG. 4 NORMAL LEAD STYPHNATE OSCILLOGRAMS USING
RCA-7102 DETECTOR TUBE

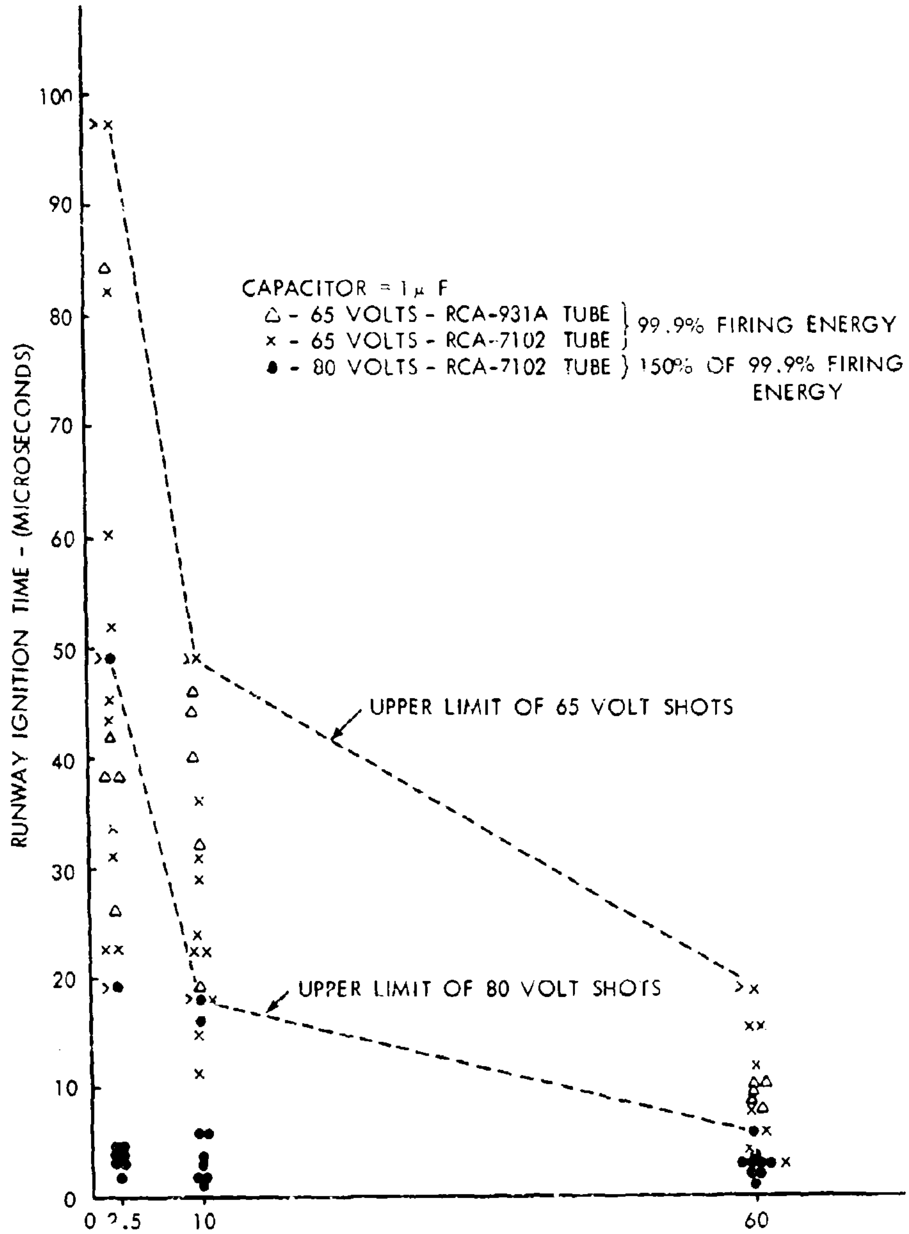
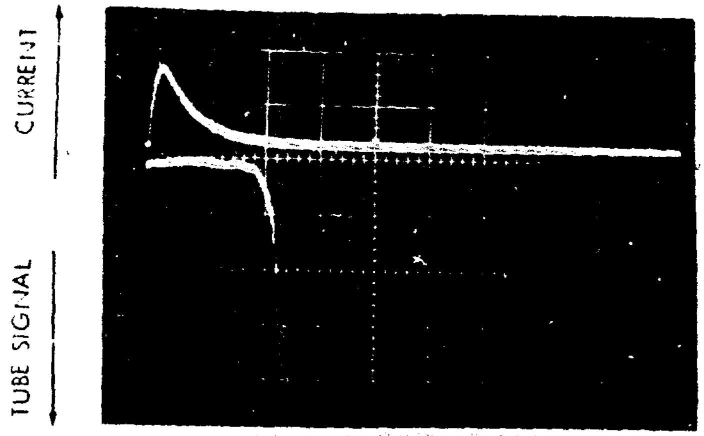
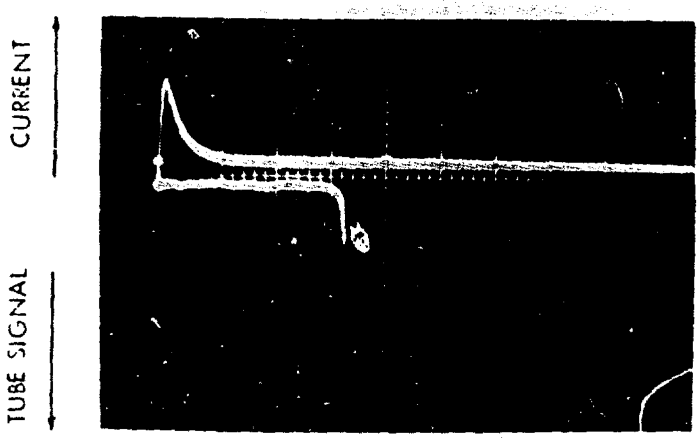


FIG. 5 EFFECT OF LOADING PRESSURE ON IGNITION TIME OF NORMAL LEAD STYPHNATE



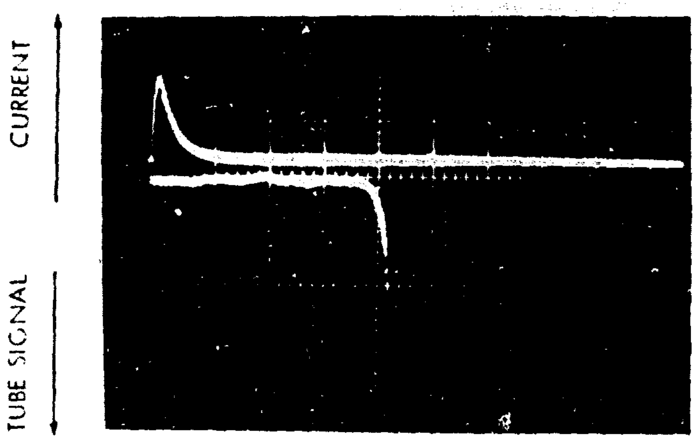
SWEEP SPEED 5μ SEC/DIV

LOADING PRESSURE - 60K PSI
CAPACITOR VOLTAGE - 65 VOLTS



SWEEP SPEED 10μ SEC/DIV

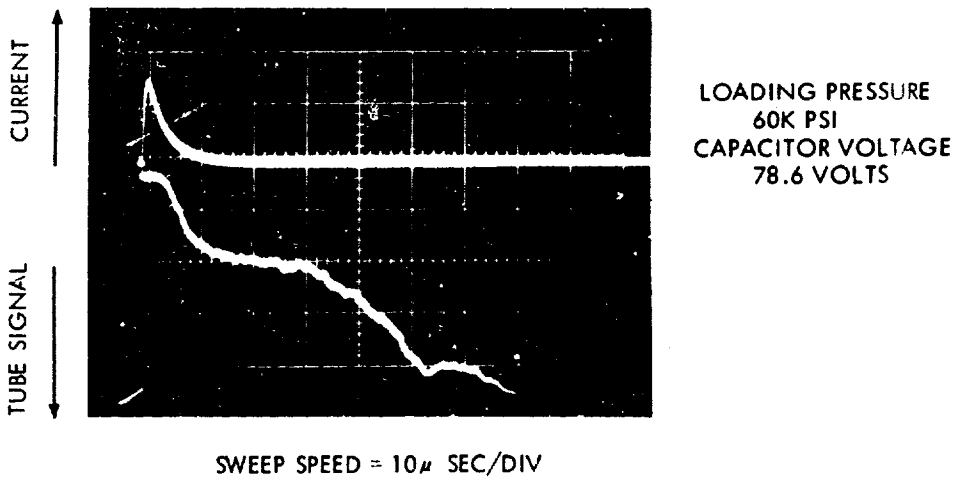
LOADING PRESSURE - 10K PSI
CAPACITOR VOLTAGE - 65 VOLTS



SWEEP SPEED 10μ SEC/DIV

LOADING PRESSURE - 2.5K PSI
CAPACITOR VOLTAGE - 65 VOLTS

FIG. NORMAL LEAD STYPHNATE OSCILLOGRAMS USING
GAMMA DETECTOR TUBE



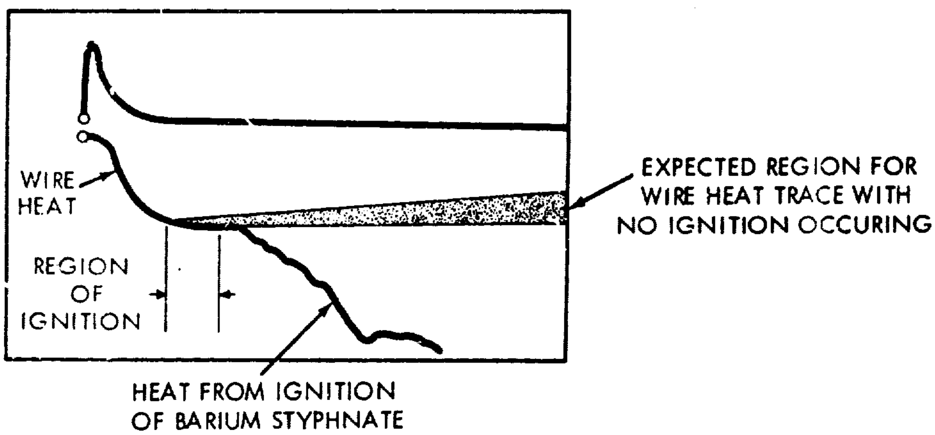
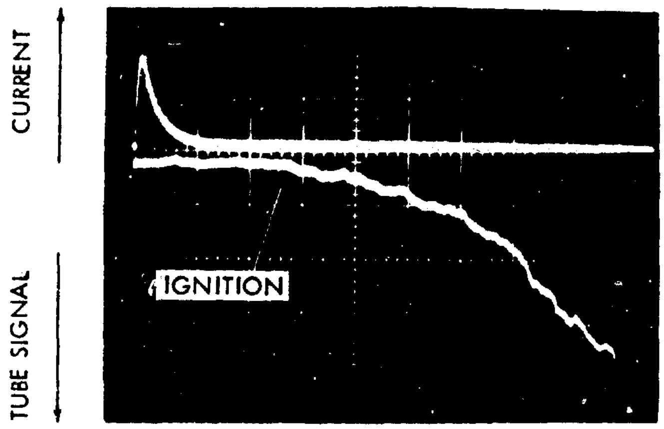


FIG. 7 OBSERVATION OF IGNITION OF BARIUM STYPHNATE USING RCA-7102 DETECTOR TUBE



SWEEP SPEED = 10 μ SEC/DIV

FIG. 8 DETERMINATION OF TIME OF IGNITION OF BARIUM STYPHNATE WITH RCA-931A DETECTOR

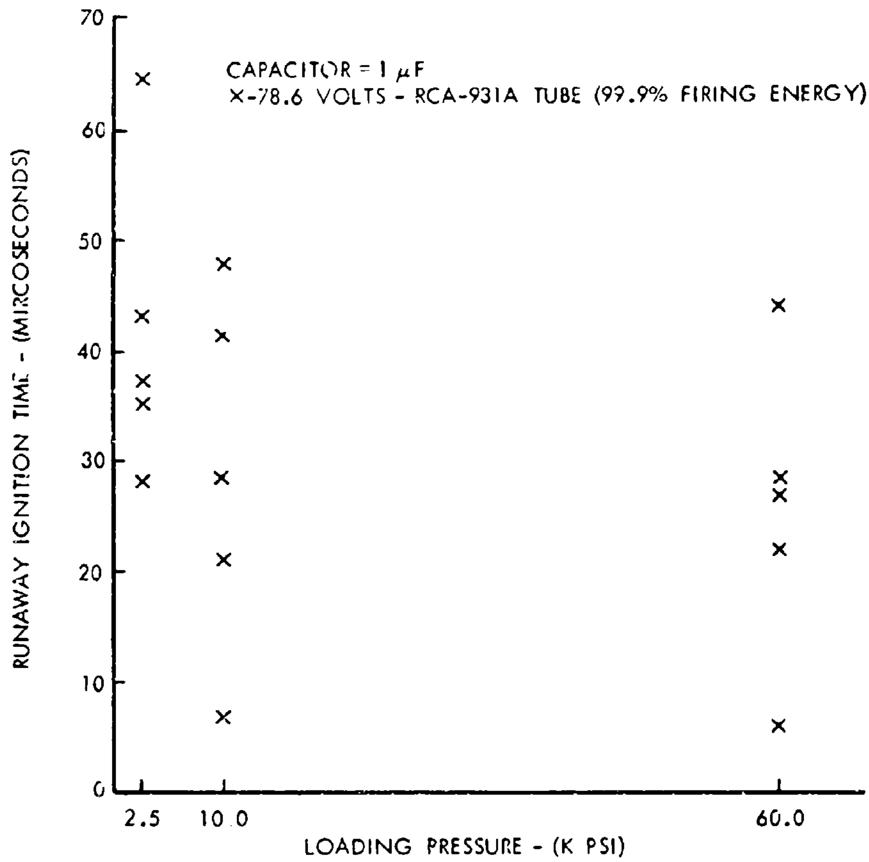


FIG. 9 EFFECT OF LOADING PRESSURE ON IGNITION TIME OF BARIUM STYPHNATE

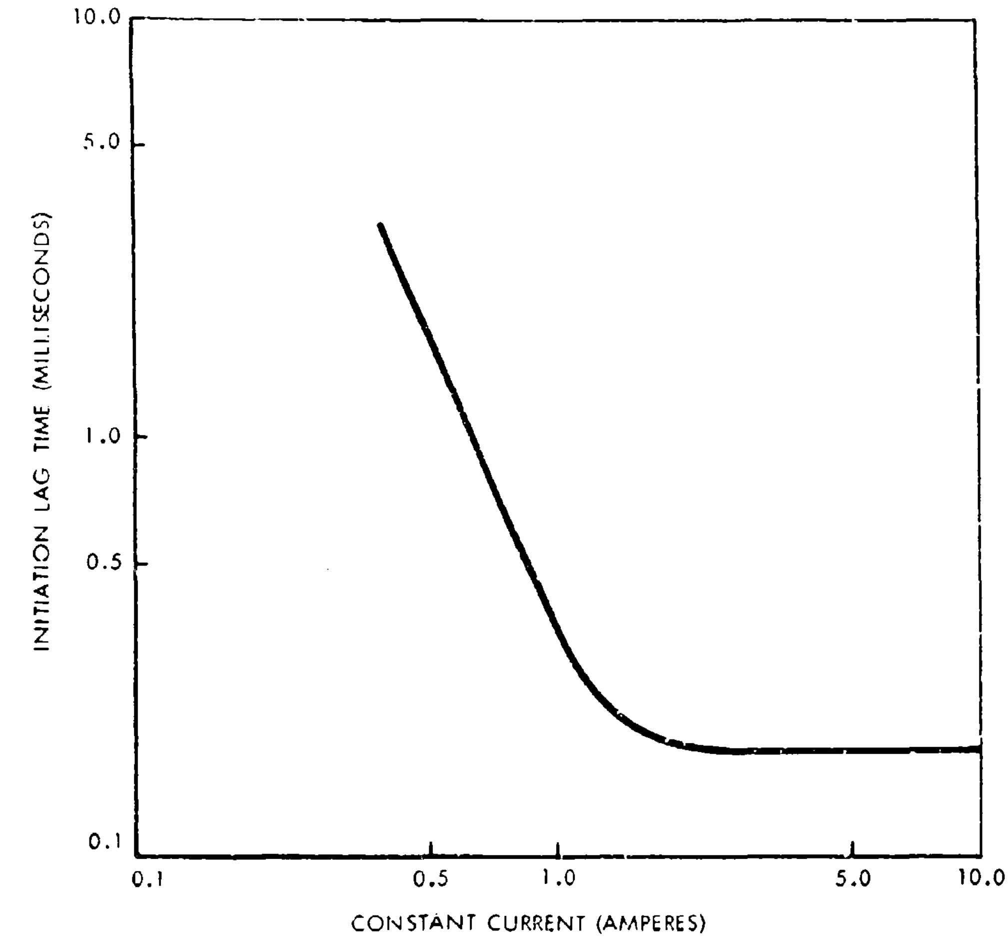


FIG. 10 FUNCTIONING TIME VS. CONSTANT CURRENT FOR DETONATOR MK57 MOD 0

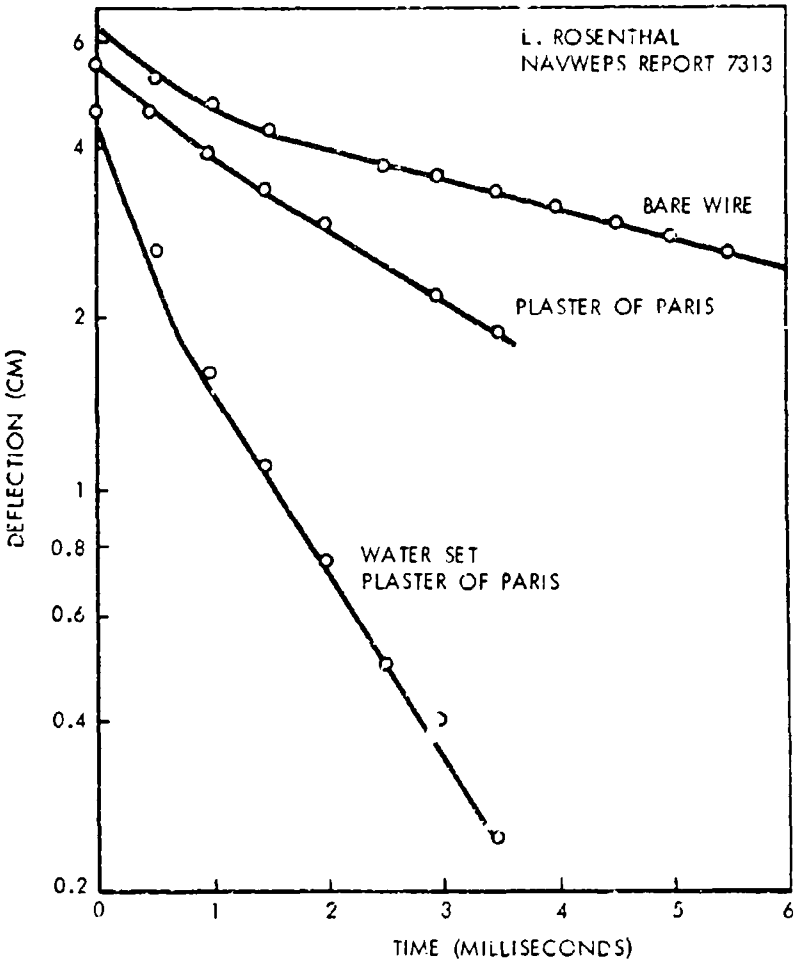


FIG. 11 PLOTS OF THE COOLING CURVES SHOWING OSCILLOSCOPE DEFLECTION AS A FUNCTION OF TIME

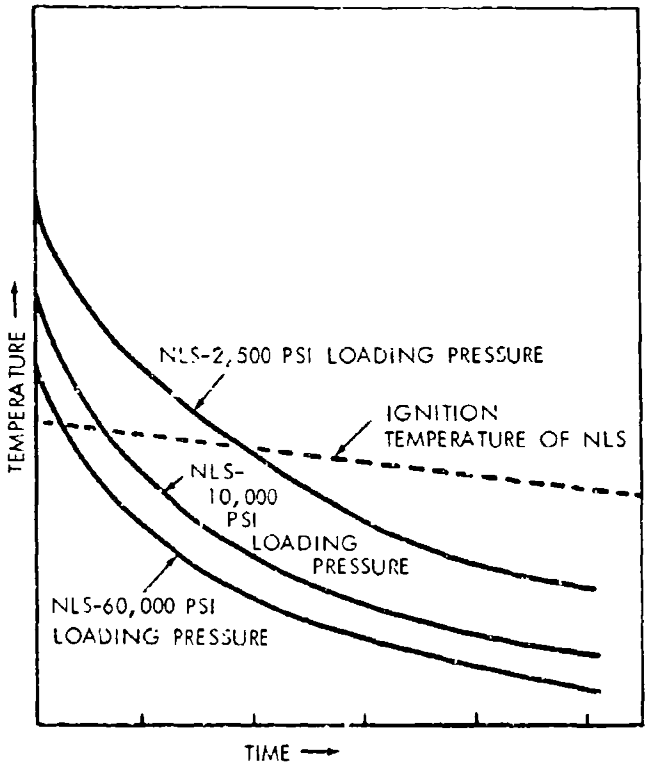


FIG. 12 RELATIONSHIP OF WIRE TEMPERATURE EXCURSIONS TO IGNITION TEMPERATURE OF NORMAL LEAD STYPHNATE

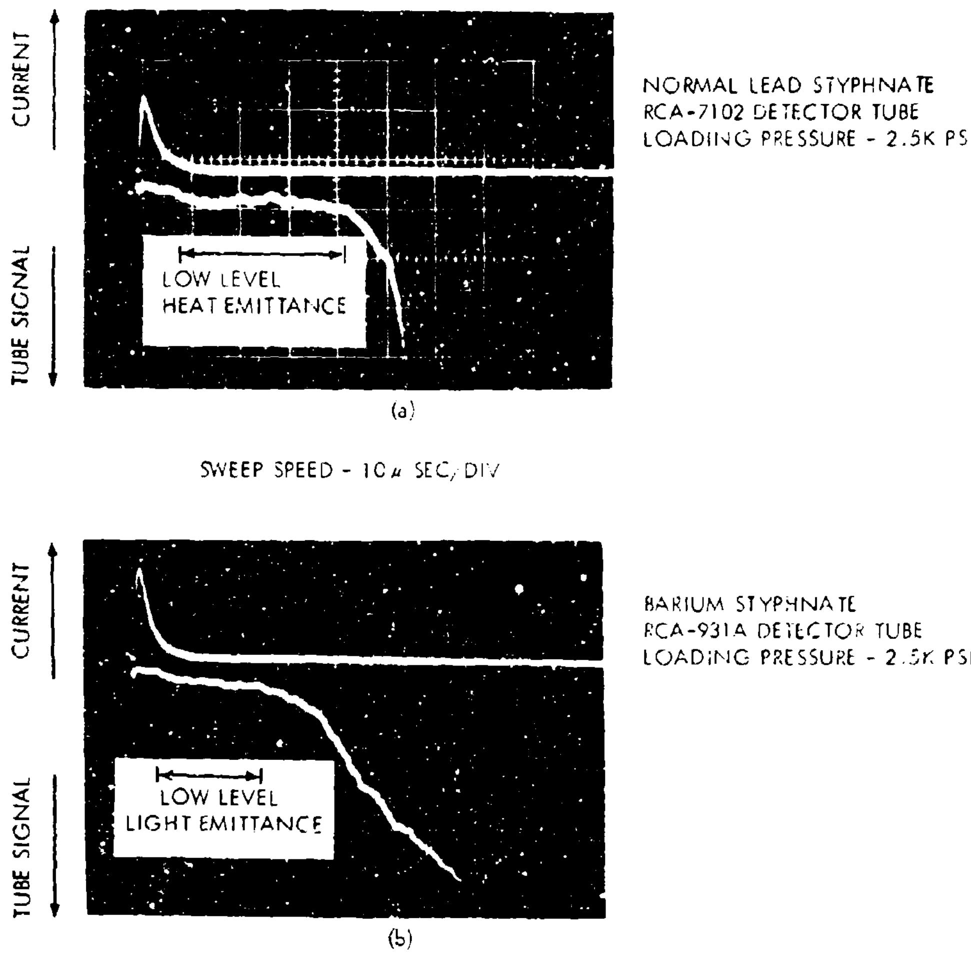


FIG. 13 OSCILLOGRAMS INDICATING LOCALIZED DECOMPOSITION

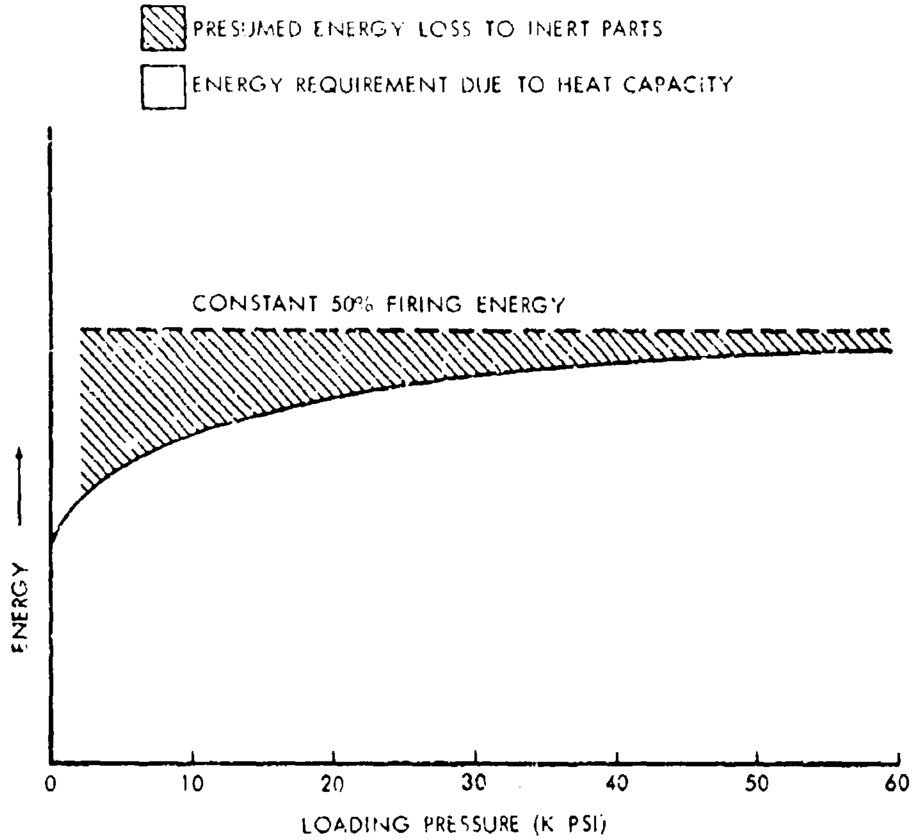


FIG. 14 POSSIBLE ENERGY DIVISION GIVING EFFECT TO CONSTANT IGNITION ENERGY REQUIREMENT OF STYPHNATES

APPENDIX A

A-1. The criterion for initiation in the method employed is the detection of radiant emission from the decomposing explosive. Actually, thermal explosive decomposition in the solid state has started slightly prior to the emission of radiation with electron rearrangement, diffusion of lattice defects, nucleation, bond changes, etc. as possible precursors, depending upon whether ionic or molecular crystals are involved. When the RCA-931A photomultiplier tube is used to observe the radiant emission, the initiation criterion is the detection of visible light (0.4 - 0.7 micron wave length). The high sensitivity of this tube results in a fairly definite oscilloscope signal when visible light is detected and would be the preferable tube when only the initiation time is of interest. However, in many cases, it is desirable to also follow the thermal excursion of the bridgewire or other thermal phenomena to relate to the time of initiation. For the experimental conditions employed, the RCA-931A photomultiplier tube can detect wire heating only when the nichrome bridgewire approaches a calculated temperature of 990°C. Part of the detection difficulty is that the wire has an approximate emitting area of only 0"001 x 0"040 = 0"00004 sq. in. Most primary explosives initiate well below 990°C and therefore only the light emitted by the explosive is usually observed by the RCA-931A tube.

A-2. The energy (E) associated with electromagnetic radiation is expressed as

$$E = \frac{hc}{\lambda}$$

where h is Planck's constant, c is the velocity of light, and λ the wavelength.

A-3. From the above formula, it can be seen that lower temperatures will result in the emittance of longer wave lengths. For this reason, trial substitution of an RCA-7102 photomultiplier tube was made for the RCA-931A. The RCA 7102 tube does not have the quantum efficiency of the RCA-913A, but can detect longer wavelengths - up to 1.1 microns. The RCA-7102 tube, for the experimental conditions employed, can detect wire heating when the bridgewire approaches a calculated temperature of 730°C. Electrons thermionically released from the tube cathode establish a limit below which weak signals cannot be distinguished from the tube noise. Amplifiers cannot be used to improve the signal since the noise is also amplified. Filters

cannot be added to the amplifier since they change the time constant of the signal. Dry ice cooling of the tube decreases the noise level and gives a slight degree of detection improvement, but not down to the level desired for examination of initiation (400 - 500°C).

A-4. The difficulty of detecting radiant emission at 500°C is shown in Table A1. Not only must one detect the less energetic longer wavelengths, but the total amount of radiant energy decreases with the fourth power of the absolute temperature. There is a single valued maximum of radiant flux density for each temperature given by Wien's displacement law

$$\lambda_{max} = \frac{2897}{T}$$

where T = absolute temperature.

A-5. For a temperature of 500°C (773°K), maximum emittance would occur at 3.75 microns. It is hoped that the rapid advances currently being made in the IR detection field will result in a photomultiplier tube which can detect the longer wavelengths enabling the examination of lower temperatures than currently possible. The light pipe material currently used would also have to be changed to transmit wavelengths longer than 1.1 microns.

TABLE A1

WAVELENGTH RANGES AND RADIANT EMISSION*

Type of Radiation	Wavelength Range μ	in % of Total at °C			
		500	1000	2000	3000
Intermediate + Far IR	20 to ∞	3	----	----	----
Near IR	1.5 to 20	97	95	64	38
Nearest IR	0.72 to 1.5	0.2	5	34	49
Visible	0.4 to 0.72	Trace	0.01	2	13
UV	less than 0.4	-----	Trace	0.01	0.5
Total Radiant Emission in W/cm^2 (approximate)		2	15	150	650

* From "Military and Civilian Pyrotechnics", H. Ellern, Chem. Pub. Co., N. Y., p89 (1968).

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13. ABSTRACT

Experiments were conducted to determine the effect of density on the required hot wire ignition energy and firing time of normal lead styphnate and barium styphnate. It was found that the ignition energy remained constant while the average ignition time decreased as the loading density was increased. It is postulated that changes in the thermal resistance between the wire and the explosive are responsible for the differences in the time of ignition. A faster transfer of energy to the explosive decreases the time the wire can act as an initiating stimulus when heated by a capacitor discharge and hence decreases the possibility of delayed ignitions.

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14 KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Hot Wire						
Initiation						
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Barium Styphnate						
Light Pipe						

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